Mon. Not. R. Astron. Soc. **000**, 1–6 (2006) Printed 20 October 2006 (MN LaTeX style file v2.2)

On the compact nature of the most luminous ULX in the Cartwheel ring

Anna Wolter[1⋆], Ginevra Trinchieri[1]† and Monica Colpi[2]‡
[1] *INAF, Osservatorio Astronomico di Brera, via Brera 28, 20121 Milano, Italy*
[2] *Dipartimento di Fisica G. Occhialini, Università degli Studi di Milano Bicocca, Piazza della Scienza 3, 20126 Milano, Italy*

ABSTRACT
We report the first detection of flux variability in the most luminous X-ray source in the southern ring of the Cartwheel galaxy. *XMM–Newton* data show that the luminosity has varied over a timescale of six months from $L_{0.5-10\mathrm{keV}} \sim 1.3 \times 10^{41}$ erg s^{-1}, consistent with the previous *Chandra* observation, to $L_{0.5-10\mathrm{keV}} \lesssim 6.4 \times 10^{40}$ erg s^{-1}. This fact provides the first evidence that the source is compact in nature and is not a collection of individual fainter sources, such as supernova remnants. The source has been repeatedly observed at the very high luminosity level of $L_{0.5-10\mathrm{keV}} \sim 1.3 \times 10^{41}$ erg s^{-1} for a period of at least 4 years before dimming at the current level. It represents then the first example of an accreting object revealed in a long lived state of extremely high luminosity.

Key words: X-rays: galaxies — Galaxies: Individual: Cartwheel — X-ray-binaries — black hole physics

1 INTRODUCTION

Very luminous off-nuclear X-ray sources were discovered in nearby galaxies with the Einstein satellite (Fabbiano et al. 1989). They were named Ultra-Luminous X-ray sources (ULXs) based on their X-ray luminosities, much higher than the Eddington limit for a solar mass black hole ($L_X \sim 1.4 \times 10^{38}$ erg s^{-1}). These luminosities may reflect beamed emission from an accreting stellar mass compact object, or super-Eddington emission, or isotropic accretion onto an intermediate mass black hole. The brightest objects, those with $L_X \gtrsim 10^{41}$ erg s^{-1}, sometimes termed Hyperluminous X-ray sources (HLXs; see Matsumoto et al. 2001; Kaaret et al. 2001), are even more intriguing, since their luminosities are closer to that of active galactic nuclei, requiring a bigger engine, stronger beaming or even extreme super-Eddington regimes. The issue of the physical interpretation of ULXs and HLXs is still quite open.

An extraordinary example of HLX is the source N.10 detected in the narrow, gas-rich star–forming ring of the Cartwheel galaxy with isotropic luminosity of $L_{0.5-10\mathrm{keV}} \sim 1.3 \times 10^{41}$ erg s^{-1} (Wolter et al. 1999; Wolter & Trinchieri 2004 - hereafter WT04; Gao et al. 2003). This is the brightest of a number of individual sources that also appear to reside in the ring, all classified as ULXs, based on their isotropic luminosities in excess of $L_{0.5-10\mathrm{keV}} = 3\times10^{39}$ erg s^{-1} (WT04).

The spatial association of the N.10 HLX and the ring–ULXs with HII complexes and young star-forming clusters suggests a physical link, thus providing an invaluable in-depth probe of the young stellar population currently present in the Cartwheel outer ring. The physical nature of the ULXs in the Cartwheel is not clear yet: they could be genuine single sources, hence accreting compact objects, or unresolved collections of supernova remnants. A way to disentangle this puzzle is to look at their variability. Variability in ULXs, covering timescales of months to a few years, has been often encountered (e.g., in the Antennae; Fabbiano et al. 2003) and was taken as evidence that they represent an apparently bright state of accreting high mass X-ray binaries (HMXBs) caught in some peculiar evolutionary stage (King 2002). Young, short lived, HMXBs hosting a neutron star or a stellar-mass black hole are common in star–burst galaxies and their number is likely to be linked with the star–formation rate of their hosting galaxy (Fabbiano 2005).

It has been proposed that HMXBs share a universal X-ray luminosity function that extends up to luminosities of 10^{40} erg s^{-1}, characteristic of ULXs (Grimm, Gilfanov, & Sunyaev 2003). WT04 have shown that the X-ray sources seen in the Cartwheel follow the same luminosity function and derive a star formation rate of 20 $M_\odot$yr^{-1} in agreement with recent radio and Far Infrared estimates (Mayya et al. 2005). The only outlier appears to be source N.10, brighter than expected at the bright end of the X-ray Luminosity Function (XLF) by a factor of 3. WT04 noticed that a higher cutoff would account for this excess in the Cartwheel XLF,

⋆ E-mail: anna@brera.mi.astro.it
† E-mail: ginevra.trinchieri@brera.inaf.it
‡ E-mail: Monica.Colpi@mib.infn.it

which would otherwise highlight a different physical origin for this exceptional HLX.

At present, the only confirmed HLX reported in the literature is the source X–1 in the starburst galaxy M82, with isotropic luminosity of a few $\times 10^{40}$ erg s^{-1} (Ptak & Griffiths 1999: ASCA baseline flux; Strohmayer & Mushotzky 2003; Dewangan et al. 2006: *XMM–Newton* observations). X–1 in M82 showed a burst, up to 10^{41} erg s^{-1}, lasting about a month during ASCA observations (Ptak & Griffiths 1999) and again with *Chandra* (Matsumoto et al. 2001; Kaaret et al. 2001). Spectral and temporal variability points to a 200M$_\odot$ intermediate mass black hole as the accreting object (Dewangan et al. 2006). If confirmed by additional observations, X–1 is the prototype of a "new" class of black holes, bridging the gap between those of stellar origin and the very massive black holes hosted in galactic nuclei (Miller & Colbert 2004). Other candidate HLXs are those in NGC 7714 ($L_X = 6. \times 10^{40}$ erg s^{-1} in the high state; Soria & Motch 2004; Smith, Struck & Nowak, 2005), in NGC2276 ($L_X = 1.3 \times 10^{41}$ erg s^{-1} in the 0.5-10 keV band; Davis & Mushotzky 2004) and in MCG-03-34-63 (ULX 1 with peak luminosity of $L_X = 1.3 \times 10^{41}$ erg s^{-1} in the 0.5-7 keV band; Miniutti et al. 2006). The majority of these objects have been observed with *XMM–Newton* only, and with limited time coverage; therefore neither a secure physical explanation nor a clear association with the host galaxy can be put forward.

The Cartwheel source N. 10 is possibly the brightest HLX known but the lack of detailed information on its variability has prevented the exclusion of an extended nature. The new data that we present here have now confirmed its compact nature.

The X-ray image of the Cartwheel shows, besides a number of point sources, the presence of hot (k_BT=0.2 keV) gas in the ring with a luminosity of $L^{gas}_{0.5-2\mathrm{keV}} = 3 \times 10^{40}$ erg s^{-1} (WT04) and suggests that more gas might be present in the near environment of the galaxy. To better study all of these components we have obtained new *XMM–Newton* observations. Here we concentrate on the properties of the HLX, leaving a more comprehensive presentation of the galaxy as a whole to a forthcoming paper. For the Cartwheel we use a distance D=122 Mpc (calculated from Amram et al. 1998, with H$_0$ = 75 km s^{-1} Mpc^{-1}) corresponding to a linear scale of 0.592 kpc/arcsec.

2 XMM DATA

The Cartwheel was observed with *XMM–Newton* on the 14-15th of December, 2004 (36 ksec; dataset [101]) and on the 21st-22nd May, 2005 (60 ksec; dataset [201]), with the pn and MOS instruments operating in full-frame mode with the thin filter applied. Standard rejection criteria were applied to eliminate high background periods that are fortunately relatively short. The net exposure times, after data cleaning, reduce to 29(24) and 50(42) ks for MOS(pn), a $\sim$ 20% reduction in time.

The two datasets were analyzed independently. We have used the standard XMM Science Analysis System tasks to prepare the data and produce images and spectra. Our primary interest, source N.10 in the *Chandra* list (WT04), falls over a bad column in MOS2 in the first observation, and in MOS1 in the second one. We will therefore consider only MOS1 and pn for the [101] observation and MOS2 and pn for the [201] observation.

We have checked consistency between the two observations by using different regions within and outside the Cartwheel. The aspect solutions of the two dataset are very similar, so that source positions do not differ between [101] and [201]. Bright field sources are expected to be mostly AGN, therefore flux variations of the order of a factor of 2 are common, so no single source can be used as a reference point. However, we have confirmed that overall the count rates are constant for a large number of sources between the two observations.

2.1 Image

We compare the pn images from the [101] and [201] observations, smoothed with an adaptive Gaussian kernel (package *csmooth* from Ciao 3.3). In Fig. 1 we plot the two images side by side. We overplot for reference the positions of *Chandra* sources, that are not at the peak of the *XMM–Newton* positions. In fact, no correction for the different aspect solutions of the two satellites has been attempted, however distances between *Chandra* and *XMM–Newton* peaks are below aspect uncertainties . Although the two images should not be used for a quantitative comparison since the two observations have different lengths and should be properly normalized and corrected for possible background differences, the graphical comparison shows variability in different areas. In particular, it is evident that the HLX is no longer the brightest source in the second observation. From the comparison between the count rates in the neighbouring sources, we have determined that the source next to it, which corresponds to *Chandra* sources N.13 & N.14, has not varied between the two observations (the count rate in the second observation is at most 15% higher than in the first one). If we assume that this is constant, then the source to the NW, corresponding to N.16 & N.17, is also constant (the same 15% increase in the count rate), but the SE source (N.7 & N.9) has faded to about half its strength in the second observation. Note that the darker colours in the image simply reflect the higher statistics available in the second exposure, which is about twice in length.

2.2 Spectrum

We extract spectra from a region of radius 10″ centred about the peak of N.10 in [101] and background from a nearby circular region devoid of sources. Appropriate response matrices for spectral analysis where generated using the SAS tasks *arfgen* and *rmfgen*. To improve on the statistics, we have binned the data so that each bin has a significance of at least 2σ. We report in Table 1 the total net counts and exposure times in seconds, after cleaning, for this extraction region.

The extraction radii for *XMM–Newton* are smaller than customary, due to the presence of many surrounding sources in the Cartwheel ring. Nonetheless they include a portion of the ring, so we expect a fraction of the diffuse underlying gas component to contaminate the HLX spectrum.

We first fit the [101] spectrum with a simple model, i.e. an absorbed power law. This results in an acceptable

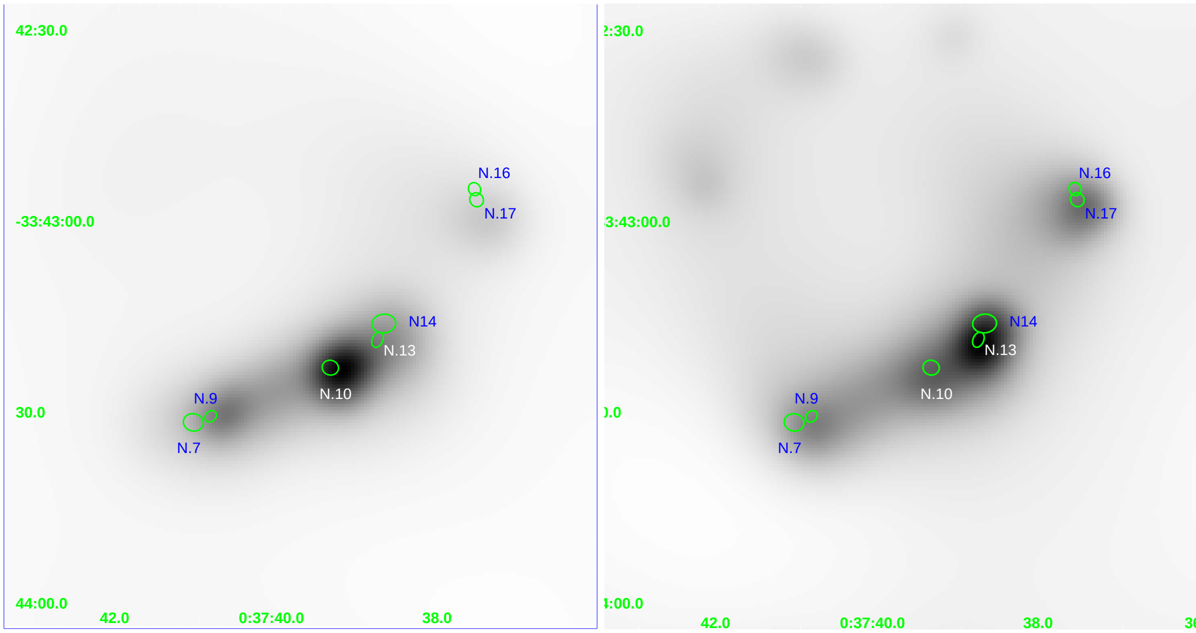

Figure 1. A smoothed grey scale image of pn data for the southwestern ring from the first observation [101], **left**, and the second [201]. **right**. The positions of the brightest *Chandra* sources are indicated. No correction for different aspect solutions has been attempted. Distances between *Chandra* and *XMM–Newton* peaks are below aspect uncertainties. In the [101] data, N.10 is clearly the brightest source; it is unresolved by *XMM–Newton*. In the [201] observation, which is longer, more details and more sources appear. The detection of a faint source at the position of N. 10 is difficult due to the close vicinity of the brighter sources N. 13&14. Notice also the relative intensity of sources N.7&N.9 and sources N.16&N.17 which is varied between the two observations. Sources N.7&N.9, N.13&N.14, and N.16&N.17 cannot be separated by *XMM–Newton*.

Table 1. Log of *XMM–Newton* Observations

Name	Date	Instrument	Net Counts[a] (0.5-10 keV)	Exp. Time sec
N.10.	12/14/2004	MOS1	80.8±9.5	29,583
	[101]	pn	202.1±14.6	24,418
N.10.	05/21/2005	MOS2	87.2±9.9	49,669
	[201]	pn	237.9±15.9	42,277

[a] in a 10″ radius, centred on RA(2000) = $00^h\,37^m\,39\overset{s}{.}38$ and Dec(2000) = $-33°\,43'\,23\overset{''}{.}08$, see text.

fit (χ^2 = 15.7 for 23 d.o.f) with a slope $\Gamma = 1.75 \pm 0.25$, low energy absorption due to an intervening column with $N_H = 1.4 \times 10^{21}$ cm^{-2} and flux $f_{0.5-10} = 6.9 \times 10^{-14}$ erg cm^{-2} s^{-1}. This is consistent with the *Chandra* results for source N.10 suggesting that the HLX is the dominant source of emission. However, due to the larger area considered and larger PSF, we expect some contribution from the underlying ring emission. As will become clearer later, this assumption is also relevant for the comparison between the two *XMM–Newton* observations. We have therefore considered a spectrum that includes all three components derived in the *Chandra* data: 1) gas, 2) unresolved binary sources,3) HLX (from WT04).

Given the limited quality of the data, we have fixed the parameters of components 1) and 2) to the same values of WT04. For the relative normalizations we used the *Chandra* values, properly rescaled to the area covered by the present region (1/10 of the emission detected by *Chandra* in the whole ring). The HLX normalization is left free, while Γ is fixed at the *Chandra* value. The details of the model are shown graphically in the rightmost panel in Fig. 2.

Table 2. Fluxes of different fit components

Component	Flux (0.5-2 keV)	Flux (2-10 keV)
HLX [101]	2.4×10^{-14}	5.0×10^{-14}
HLX [201]	1.2×10^{-14}	2.3×10^{-14}
gas	2×10^{-15}	–
unresolved binaries	1×10^{-15}	1.3×10^{-15}

The HLX is indeed the brightest component in the 10″ radius region; see Table 2 for fluxes of the different components. The intrinsic luminosity of the HLX is $L_{0.5-2\rm keV} = 4.6 \times 10^{40}\,\rm erg\,s^{-1}$ and $L_{2-10\rm keV} = 8.7 \times 10^{40}\,\rm erg\,s^{-1}$.

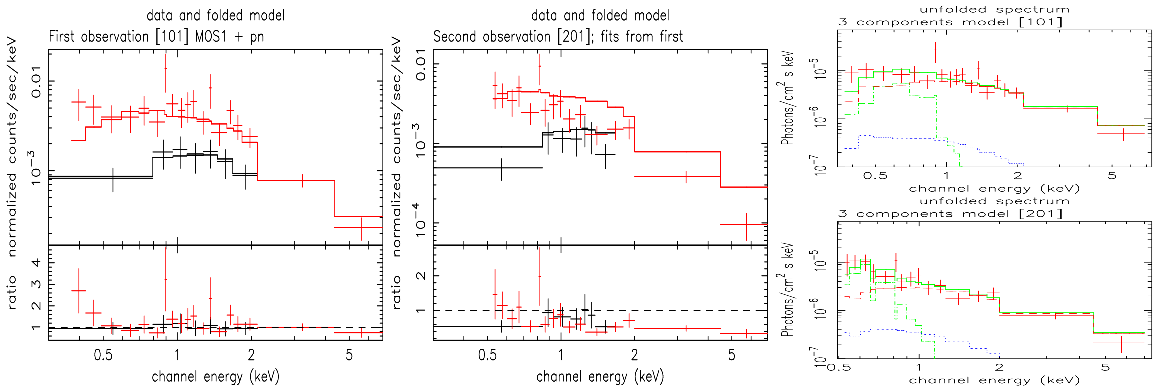

Figure 2. Left: spectrum of [101], fit as described in the text. Centre: spectrum of [201] with fit from [101]. Right: Unfolded spectrum, from pn data only for clarity, showing the three components at the best fit values. The difference between top [101] and bottom [201] is only the normalization of the 'HLX' component [and the binning scheme].

We then used the same extraction region, and the same binning scheme for the [201] dataset. We obtained about the same number of net counts in spite of the longer observing time. Again, the single power law gives an acceptable fit ($\chi^2 = 18.8$ for 21 d.o.f.) with parameters consistent to [101], and a flux about half. If we apply the same complex spectral model of [101], with the same parameters, we find a large discrepancy with the data ($\chi^2 > 170$ for 21 d.o.f.) as shown in Fig. 2 (Centre). In particular we notice that the points above 0.8 keV are systematically lower than the model. If we make the reasonable assumption that both the diffuse gas and the unresolved point source components have not varied, and let only the normalization for the HLX component vary, we obtain a good fit for a normalization that is about 1/2 that of [101] ($\chi^2 = 21.13$ for 23 d.o.f.). Given the data quality and the complexity of the spectral model, testing a spectral variation in this component is unrealistic. We therefore cannot comment on spectral variations between a high and a low state expected for binary sources. However we can reasonably state that the HLX has dimmed by at least a factor of two in the 6 months between the two observations. The unabsorbed flux of N.10 in this second observations at the formal best fit values is reported in Table 2. The corresponding luminosity is at most $L_{0.5-2\mathrm{keV}} = 2.0 \times 10^{40}$ erg s^{-1} and $L_{2-10\mathrm{keV}} = 3.8 \times 10^{40}$ erg s^{-1}.

2.3 Light curve

The evidence for variability during the *XMM–Newton* observation prompted us to look at the long term behavior of the source. We construct the light curve of source N.10 by using all the available datasets (Fig. 3). We extract net counts from a 10″ radius region in the 0.3-2.5 keV band, to match the limited energy band of the HRI, and use a nearby large circle devoid of sources for background. We convert count rates to flux by using the *Chandra* fit with a power law and conversion factor from PIMMS (see WT04). Of course cross calibration uncertainties are possible between different instruments, and we cannot be sure that the shape of the emission was the same at all times, however these uncertainties are probably small in the band considered.

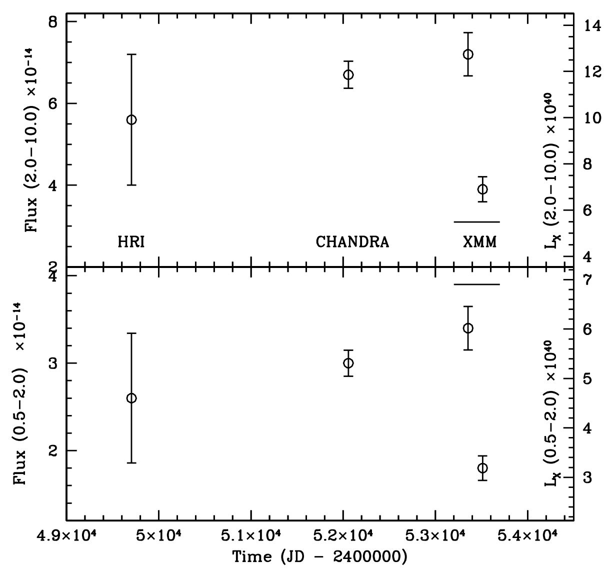

Figure 3. Long term light curve in the soft (lower panel) and hard (upper panel) energy band, over an interval of about 10 years. The two *XMM–Newton* points that define the variation are not subject to cross-calibration uncertainties. All fluxes are computed with the same spectral shape, i.e. power law with $\Gamma = 1.6$ and $\mathrm{N_H} = 3.6 \times 10^{21}$ cm^{-2}; see fit to *Chandra* data in WT04. Right axis reports luminosities computed assuming the Cartwheel distance.

Dates, instruments, count rates and fluxes in both the soft and hard band, extrapolated from the same model, are reported in Tab. 3. From inspection of the light curve we deduce that the HLX was in a brighter state from 2001 to 2004. The HRI errorbar is consistent at the lowest level with a "ring-only" contribution, but an enhancement of the emission was visible in the area in the HRI data, to indicate that the source was probably also in this bright state since 1994 (see Wolter et al. 1999). The source became significantly fainter in the six months between the 2004 and 2005 *XMM–Newton* observation, assuming a "ULX" status.

Table 3. Summary of all observations of N.10

Date	JD	Instrument	Count rate (0.3-2.5 keV)	Flux (0.5-2 keV)	Flux (2-10 keV)
1994 Dec 9-23	2449696-2449710	*ROSAT* HRI	$3.79 \pm 1.08 \times 10^{-4}$	2.6×10^{-14}	5.6×10^{-14}
2001 May 26-27	2452056-2452057	*Chandra* ACIS-S	$5.30 \pm 0.26 \times 10^{-3}$	3.0×10^{-14}	6.7×10^{-14}
2004 Dec 14-15	2453354-2453355	*XMM–Newton* pn	$7.8 \pm 0.57 \times 10^{-3}$	3.4×10^{-14}	7.2×10^{-14}
2005 May 21-22	2453512-2453513	*XMM–Newton* pn	$4.2 \pm 0.33 \times 10^{-3}$	1.8×10^{-14}	3.9×10^{-14}

3 DISCUSSION

Spectral properties and variability in some ULXs (e.g. Makishima et al. 2000) suggest that we are witnessing accretion onto a compact object, in a binary system. However, no universal model exists. ULXs might be stellar mass black holes with anisotropic X-ray emission due to mechanical beaming (King et al. 2001), or relativistic beaming from a jet (Mirabel & Rodriguez 1999; Körding et al. 2002), or stellar mass black holes accreting at super-Eddington rates (Begelman 2002). The most challenging model for the HLXs, given their extreme luminosities, is that of a binary system hosting a 10^{2-4} $M_\odot$ black hole (e.g. Colbert & Mushotzky 1999). Intermediate mass black holes may form from the collapse of very massive stars born through stellar runaway collisions in dense star clusters (Portegies Zwart & McMillan 2002; Gurkan et al. 2004). In such a young environment, the intermediate mass black hole may gain a massive donor star ($\gtrsim 20$ $M_\odot$) through tidal events (Baumgardt et al. 2005) or dynamical interactions (Blecha et al. 2006). This system will be able to sustain luminosities as high as 10^{40-41} erg s^{-1} as seen in the very bright ULXs (Patruno et al. 2005; Madhusudhan et al. 2006). Spatial association of X-ray sources with young star cluster has been searched for a number of ULXs (Kaaret et al., 2004) but has not been firmly established yet. The whole ring of the Cartwheel consists of bubbles and condensations (Struck et al. 1996) and the neighbourhood of N.10 is no exception. Given the distance of the galaxy any small misalignment between X-ray and optical (HST) positions implies kpc scale distances, so a precise determination of the optical counterpart is hard, without a proper absolute cross-calibration of the two images. In any case, the association with an environment of massive and young stars is almost certain.

The *XMM–Newton* observatory has revealed a factor of two dimming in the flux of source N.10 in the Cartwheel, over a timescale of ~ 6 months. Although this kind of variability has been observed in other ULXs, in the N.10 case it provides the first evidence against the hypothesis that the source is a chance superposition of fainter sources such as young supernova remnants, and suggests that it is a truly compact source. The estimated age of the southern ring (< 10 Myr), and the lack of radial spread of its sources, indicate that source N.10 is closely linked to the active star forming episode and its youth suggests that the hypothetical intermediate mass black hole present in N.10 had a high chance of capturing the massive companion star through a tidal event (Baumgardt et al. 2005). The decline in flux by a factor of two brings the source down to the luminosity level of many other ULXs. So, one may suspect that variability (which is seen in the directions of both increasing or decreasing luminosity; Fabbiano et al. 2003) occasionally transform ULXs in HLXs and viceversa. The dimming of source N.10 is such that its flux is now consistent with the star–formation–rate normalized XLF of the Cartwheel (assumed to be constant as observed in other well monitored sources such as the Antennae, Zezas et al. 2004), demonstrating continuity, at the brightest fluxes, with the HMXBs and ULXs. Most probably, then, ULXs and HLXs are low and high states respectively of the same class of sources. Continuity in the XLF with HMXB suggests also that ULXs might not be an entirely different phenomenon: they may represent extreme high luminous states related to the fainter accreting binaries. At present we can not exclude that source N.10 is powered by an intermediate mass black hole since we lack detailed information on the spectrum and on the variability properties due to the limited statistics available. Deep optical and radio observations might give further insight into the nature and the environment of such source. On the other hand, source N. 10 may be a HMXB accreting anisotropically onto a stellar mass black hole in a peculiarly high luminosity state (King 2002, 2004). We can reject instead the possibility that a rotation powered Crab-like pulsar (Perna & Stella 2004) is hosted in the HLX, since a luminosity decay by magnetic braking over a time scale of six months would require the occurrence of a young pulsar of comparable age. This is inconsistent with the stability of the light curve observed over the last 4 or 10 years, from the *ROSAT*, *Chandra* and *XMM–Newton* composite data.

King & Dehnen (2005) suggested recently that HLXs differ substantially from ULXs, and are naked, tidally stripped nuclei of dwarf galaxies hosting a massive relatively bright black hole. For substantial tidal stripping to occur, a very close distance of approach (~ 200 pc) is required for the impinging dwarf inside the main galaxy. This is just the distance of X–1 from the core of M82, which the authors interpret as an active relic of a naked dwarf core. For source N.10 this scenario runs into serious difficulties. The southern ring of the Cartwheel is a coherent expanding wave of star formation associated to a strong gaseous density wave excited by a collisional perturbation with a nearby galaxy. Given the gas-dynamical origin of the ring it is unrealistic to believe in a chance coincidence of source N.10 with a stripped core of a dwarf passing by. We have also investigated the possibility that we are observing a background AGN. From the extragalactic LF (Hasinger et al. 1993) we derive a chance coincidence for a background source of $\leqslant 2 \times 10^{-3}$ for the whole ring at the flux of the *Chandra* detection of source

N.10. This is a small but non negligible possibility, which however we consider unlikely.

Individual most luminous ULXs, termed here HLXs, may represent occurrences of accretion episodes onto intermediate mass black holes. Source N. 10 in the Cartwheel, together with source X-1 in M82, could be the cleanest example. Whereas source X-1 in M82 stayed in the HLX state for timescales of hours, source N.10 in the Cartwheel is the longest lived HLX, having been observed in a time frame of at least 4 years to be as bright as $L_{0.5-10\mathrm{keV}} \sim 1.3 \times 10^{41}$ $\mathrm{erg\,s^{-1}}$. We thus expect that other bright ULXs may share variability of this kind and become so bright to be observed at the HLX level. We cannot establish at the moment whether HLXs represent an altogether physically distinct class of objects as suggested e.g. by King & Dehnen (2005), or an higher luminosity transient–state of ULXs.

Repeated observations of the Cartwheel at high resolution are the best way to properly determine the variability pattern of source N.10 and the best mean to properly study this extreme source, which could be the first example of a long lived HLX in our local universe.

ACKNOWLEDGMENTS

We thank Angela Iovino for useful discussions. We acknowledge partial financial support from the Italian Space Agency (ASI) under contract ASI-INAF I/023/05/0. This research has made use of SAOImage DS9, developed by the Smithsonian Astrophysical Observatory. This work is based on observations obtained with XMM-Newton, an ESA science mission with instruments and contributions directly funded by ESA Member States and the USA (NASA).

REFERENCES

Amram, P., Mendes de Oliveira, C., Boulesteix, J., Balkowski, C. 1998, A&A, 330, 881
Begelman, M.C. 2002 ApJ, 568, L97
Baumgardt, H., Hopman, C., Portegies Zwart, S., Makino J. 2005, astro-ph/0511752
Blecha, L., Ivanova, N., Kalogera, V., Belczynski, K., Fregeau, J., Rasio, F. 2006, ApJ, 642, 247
Colbert, E.J.M., & Mushotzky, R.F. 1999, ApJ, 519, 89
Davis, D.S., & Mushotzky, R.F. 2004, ApJ, 604, 653
Dewangan, G.C., Titarchuk, L., & Griffiths, R.E. 2006, ApJ, 637, L21
Fabbiano, G. 1989, ARA&A, 27, 87
Fabbiano, G. 2005, ARA&A, submitted, astro-ph/0511481
Fabbiano, G., Zezas, A., King, A.R., Ponman, T.J., Rots, A., & Schweizer, F. 2003, ApJ, 584, L5
Gao, Y, Wang, Q.D., Appleton, P.N., Lucas, R.A. 2003, ApJ, 596, 171
Grimm, H.-J., Gilfanov, M., & Sunyaev, R. 2003, MNRAS, 339, 793
Gurkan, M.A., Freitag, M., Rasio, F.A. 2004, ApJ, 604, 632
Hasinger, G., et al. 1993, A&A, 275, 1
Higdon, J.L. 1995, ApJ 455, 524
Kaaret, P., et al. 2001, MNRAS, 321, L29
King, A.R., Davies, M.B., Ward, M.J., Fabbiano, G., Elvis, M. 2001, ApJ, 552, L109
King, A.R. 2002, MNRAS, 335, L13
King, A.R. 2004, MNRAS, 347, L18
King, A.R., & Dehnen, W. 2005, MNRAS, 357, 275.
Körding E., Falcke, H., Markoff, S. 2002, A&A, 382, L13
Madhusudhan, N., Justham, S., Nelson, L., Paxton, V., Pfahl, E., Podsiadlowski, P., & Rappaport S. 2006, ApJ, 640, 918
Makishima K., et al 2000, ApJ, 535, 632
Matsumoto, H., Tsuru, T.G., Koyama, K., Awaki, H., Canizares, C.R., Kawai, N., Matsushita, S., Kawabe, R. 2001, ApJ, 547, 25
Mayya, Y. D., Bizyaev, D., Romano, R., Garcia-Barreto, J.A., Vorobyov, E.I. 2005, ApJ, 620, 35
Miller, M.C., & Colbert, E.J.M. 2004, IJMP-T 13 1
Miniutti, G., et al. 2006, MNRAS, astro-ph/0607501
Mirabel, I.F., & Rodriguez, I. 1999, ARA&A, 37, 409.
Patruno, A., Colpi, M., Faulkner, A., & Possenti, A. 2005, MNRAS, 364, 344.
Perna R., & Stella, L. 2004, ApJ, 615, 222
Portegies Zwart, S.F., & McMillan, S.L.W. 2002, ApJ, 576, 899
Ptak, A., & Griffiths, R. 1999, ApJ, 517, L1
Smith, B.J., Struck, C., Nowak, M.A, 2005, AJ, 129, 1350
Soria, R., & Motch, C. 2004, A&A, 422, 915
Strohmayer, T.E., Mushotzky, R.F. 2003, ApJ, 586, L61
Struck, C., Appleton, P.N., Borne, K.D. and Lucas, R.A. 1996, AJ, 112, 1868
Wolter, A., Trinchieri, G., & Iovino, A. 1999, A&A, 342, 41
Wolter, A., & Trinchieri, G. 2004, A&A, 426, 787 (WT04)
Zezas, A., Fabbiano, G., Baldi, A., King, A.R., Ponman, T.J., Raymond, J.C., Schweizer, F. 2004, IAU Colloquium 194, Revista Mexicana de Astronomìa y Astrofisica, 20, 53

This paper has been typeset from a TEX/ LATEX file prepared by the author.